

A Preliminary Study of the Energy Expenditure and Food Requirements of Women Workers.

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The large share which women have taken during the war in industrial work has brought out the importance of possessing reliable data on which to base a fair assessment of their share in the available food supply, and has also revealed the paucity of our knowledge with regard to the energy expenditure of women workers under factory conditions.*

The food requirements of manual workers are obviously to the largest extent dependent on the energy expenditure of the individual. A scientific system of assessing this expenditure, expressed in calories, may be based on two methods. In the first, which may be called the statistical method, we arrive at the result by indirect means. The actual amounts of the various foodstuffs consumed by a large number of workers are weighed, and from their contents in proteins, fats and carbohydrates, the energy value of the food consumed is calculated. The second method, which may be called the direct method, aims at the direct determination by suitable methods of the energy expenditure of the worker during sleep, recreation, and work. This procedure is *a priori* preferable to the statistical one, but owing to inherent practical difficulties, it has not so far been applied to industrial workers. It is obvious that the complicated and expensive installations necessary for direct calorimetry are unsuitable for work under factory conditions. It was possible, however, to make use in the workshop of the method of indirect calorimetry, the general application of which has been so greatly extended by the introduction of the Douglas bag method.†

An opportunity for carrying out such an investigation was afforded by the establishment of a Training School for Munition Workers at King's College, London, under the direction of Prof. A. H. Jameson, Professor of Civil Engineering. The following report of a research, which was undertaken at Dr. Cathcart's suggestion, as the first of a series, deals with women performing lathe work only. The number of experiments were, unfortunately,

* Only in two cases has the energy metabolism of women workers been investigated, namely that of typists, by Carpenter ('Journ. Biol. Chem.,' vol. 9, p. 231 (1911)), and that of women occupied in sewing, housework, washing, etc., by Becker and Hämäläinen ('Skand. Arch. of Physiol.,' vol. 31, p. 198 (1914)). The conditions in both cases were not such as obtain in factories.

† 'Journ. Physiol.,' vol. 63, p. xvii (Proc.) (1911).

not so numerous as was at first intended, owing to the cessation of the activities of the Training School after the declaration of the Armistice. Nevertheless, the close agreement of the values obtained for the "standard" (basal) metabolism (see p. 54) makes the correctness of the other results probable, and justifies the assumption that even a larger number of working experiments would not materially affect the general conclusions.

1. *Plan of Experiments.*

The general plan of the experiments was to collect data from as many subjects as possible, which would allow the energy expenditure of an average adult woman during 24 hours to be calculated. This period is divided in the everyday life of the worker into three periods of approximately eight hours each, *i.e.*, the periods of sleep, work, and recreation.

(a) *Metabolism during Sleep.*—The energy expenditure during sleep may be assumed, for the purpose of this investigation, to be only slightly smaller than that during complete muscular rest in the post-absorptive condition, *i.e.*, 12–14 hours after the last meal. This value, which might conveniently be termed the "standard" metabolism in preference to the usual term "basal" metabolism* was determined for each subject. The experiments were made at 9 A.M., the subjects coming to work without having partaken of any breakfast, and having rested in a reclining position some time before the experiment. All experiments were made during complete muscular repose, the subjects lying comfortably on a couch.

(b) *Metabolism during Work.*—The following short details about the organisation of the Training School are necessary for the description of the "work" experiments. The school had for its purpose the training of women for the manufacture of aeroplane components, necessitating the use of the lathe. The course extended over eight weeks, of which three weeks were spent in the preliminary shop for general training and five weeks in the aeroshop for work on machines as actually used in the industry. The working hours were from 9 A.M. to 6 P.M. including meal times (12–1 and 4–4.15). Factory discipline was maintained. The workshops were well lighted and heated by radiators. Observations made on several occasions with Hill's kata-thermometer† tend to confirm the subjective impression that the shops were well ventilated and the working conditions comfortable (see Appendix, Table I).

The method of instruction consisted in sets of progressive exercises in

* See Krogh, 'The Respiratory Exchange of Animals and Man,' London, 1916.

† 'Rep. Loc. Govt. Board,' New Series, No. 100 (1914).

both operating and setting.* The operations included parting, recessing, turning (hand-feed), screw cutting, hand-chasing screws, boring (hand-feed and from headstock), etc. Two types of lathes were in use: (1) centre lathes (6", 7", and 9") and (2) Herbert capstan lathes (No. 4 medium and No. 9 heavy). The latter, as used in the manufacturing industrial shops, were supplied by the Ministry of Munitions.

In absence of any simple methods for the actual measurement of work performed, a somewhat arbitrary division became necessary into light, medium, and hard work. The operations of parting, screw-cutting, or chasing, turning, etc., which necessitated merely the exertion of a slight constant pressure during the turning of a handle, were classified as "light" work. Rough turning, boring (hand-feed), and similar operations represented "medium hard" work, whilst operations involving several turns of the capstan or boring heavy work from headstock, etc., were taken to represent "hard" work. The "work" experiments by each subject were not carried out consecutively, but on different days, usually in the afternoon. In each category of work all the subjects performed as far as possible the same operations on the same type of lathe. For the final calculation of the energy output during the eight hours' working period, it was considered, after investigation of the actual conditions, that not more than two hours should be allotted to hard work, and that the mean between "light" and "medium hard" work would fairly represent the remaining six working hours.

(c) *Metabolism during Recreation.*—For various reasons, it is obvious that any estimate of the energy expenditure during the active non-working period can only be approximate. By taking the energy expenditure during walking, standing, and sitting as a basis of calculation, we shall probably err in underestimating rather than in overestimating the bodily activities of the average working girl during recreation hours. As a result of personal enquiries from the subjects of this study, it would seem that these three forms of activities would be fairly apportioned by ascribing $1\frac{1}{2}$ hours to walking, $3\frac{1}{2}$ hours to sitting, and 3 hours to standing. In all cases the energy expenditure during standing was estimated whilst the subject stood in an easy relaxed position, and some time after the performance of any active work. The walking experiments were carried out on the level, the stone-paved corridor of the College (80 m. long) serving as a convenient course, necessitating only one turning movement in a two minutes' walk.

* The exercises were arranged by the manager of the school, Mr. H. G. Taylor, Lecturer on Engineering, King's College, to whom I am greatly indebted for information and kind help in carrying out this investigation.

2. *Technique.*

The general method of estimating energy expenditure by indirect calorimetry with the help of the Douglas bag is now too well known to require further description.* A bag of about 50 litres content was used. Although a careful test showed that no appreciable loss of CO₂ occurred until after two hours from filling the bag (see Table II, Appendix), the expired air was measured and analysed immediately after each experiment. A Wright's wet meter reading to 1 c.c. was used for the measurement, and the analyses were carried out in Haldane's apparatus. Potassium pyrogallate, as absorbent for oxygen, was found by far preferable in this form of apparatus to sodium hydrosulphite, which is recommended by Durig† for use in the Zuntz-Geppert apparatus. All analyses were made in duplicates, and results showing a difference greater than 5/100 per cent. were discarded and repeated.

In a few preliminary experiments the valve, head and mouthpiece was used as supplied by the makers, Messrs. Siebe, Gorman & Co., Ltd. It became soon evident that this arrangement, excellent as it is for investigation by trained observers on themselves, had serious drawbacks when applied to girl munition workers under factory conditions. The main objections were raised (1) against the nose-clip and mouthpiece, which latter besides being painful to the gums in some cases, gives rise to excessive salivation in all; (2) against the position of the corrugated rubber tubing which coming from the valve passes over the head to connect with the bag. This wide tubing, intersecting the field of vision, interferes seriously with the power of the subject to make the fine adjustments necessary in lathe work.‡ The second objection was successfully overcome by the construction of a new double-acting valve in which the expired air passes downwards. A detailed description of this valve is, however, unnecessary as it still necessitated the objectionable use of the mouthpiece.

It seemed possible to avoid all the above raised objections by employing a suitable face mask, and thus reverting to the principle which was first introduced into the technique of respiration experiments by Edward

* For full working details see E. P. Cathcart, 'Journ. Roy. Army Med. Corps,' November, 1918.

† 'Biochem. Zeitschr.,' vol. 4, p. 65 (1907).

‡ A further objection, from the investigator's point of view, is against the clicking noise made by the mica discs of the valves which, by attracting the attention of the subject, gives rise to wilful and intentional breathing irregularities. This was easily overcome by using the excellent rubber valves recommended by Y. Henderson, 'Journ. Biol. Chem.,' vol. 33, p. 47 (1918).

Smith* 60 years ago. An excellent face mask which covers the nose and the mouth, leaving the rest of the face exposed, is made by Messrs. Siebe, Gorman and Co., Ltd., for a different purpose.

Firemen's Smoke Mask.—By simply reversing the valves of this apparatus it can be at once adapted for the present purpose, the connecting rubber tubing passing downwards and resting on the shoulder without interfering with the freedom of movement of the subject. It was found advisable to drill an additional series of holes into the metal part of the valves, thus ensuring a perfectly free passage of inspired and expired air. The mask can be easily adapted to any shape of face, owing to the flexibility of the inflated rubber cushion which enables an air-tight fit to be made. There is no doubt a serious difficulty, when using a mask, in obtaining an air-tight fit in men with hairy or sunken cheeks, but as all the subjects of this investigation were young women with smooth and well filled out faces, this difficulty was not met with. The wearing of the mask does not interfere to any extent with the natural rhythm of breathing, as does the mouthpiece and nose-clip. Whereas, with the latter, persuasion was necessary to induce the subjects to carry out the experiments, no objections were raised against the face mask—an important consideration in an investigation in which a satisfactory result largely depends on the good will of the subject. Approximately three-quarters of the experiments were carried out with the help of the face mask, but since some comparative experiments made on myself (see Table III, Appendix), and on one of the subjects gave identical results, it was thought unnecessary to distinguish between them in the following Tables.

3. *Subjects.*

Six young women volunteered as subjects for this investigation. One of them, Subject F, finding manual work too strenuous, returned to her previous occupation (nursing) before the completion of the whole series of observations. Their ages were from 18–29 years and the character of their previous occupation, which is to some extent reflected in their calorie expenditure during work (see later) had been different in each case. Only one of them (Subject A) had 18 months' previous experience of munition work of a different type, a fact which partly explains her small energy expenditure

* 'Phil. Trans.,' vol. 149, p. 681 (1859). The remarkable work of this investigator has received a good deal of unjust criticism at the hands of later German workers, whilst many of his original observations have been passed over or were rediscovered (such as the importance of determining the standard (basal) metabolism in the post-absorptive condition, the stimulating influence of proteins on the gaseous metabolism, its increase during walking, and on the treadmill, etc.).

during work (see later). They continued in good health during the time of the observations, care being taken to discontinue the working experiments during the period of catamenia, so as to exclude a possible influence of this factor.* The respiration and pulse rate was recorded in the experiments made in the resting, sitting, and standing positions, but their observation was not found feasible during the working experiments. The diet of the subjects was the ordinary mixed diet in which, under the war conditions then prevailing, the share of carbohydrates may perhaps have been larger than normally. Their meals during working hours were consumed in the refectory provided by the authorities and were probably more or less of uniform character.

The energy expenditure per hour and per square metre of body surface has been taken as the basis for comparison of the results,† and in order to enable comparison with previous work the calorie expenditure calculated per kilogramme of body weight per hour has also been included. The area of the body surface was calculated according to the formula of D. and E. F. Du Bois‡ from which a chart was constructed on a scale sufficiently large to read the value to the third place of decimals.

The weight of the subjects (without clothes) was recorded by Mrs. M. C. Rosenheim, to whom I am also indebted for much valuable assistance during the whole course of these experiments. The statistical data of the subjects are given in the following Table:—

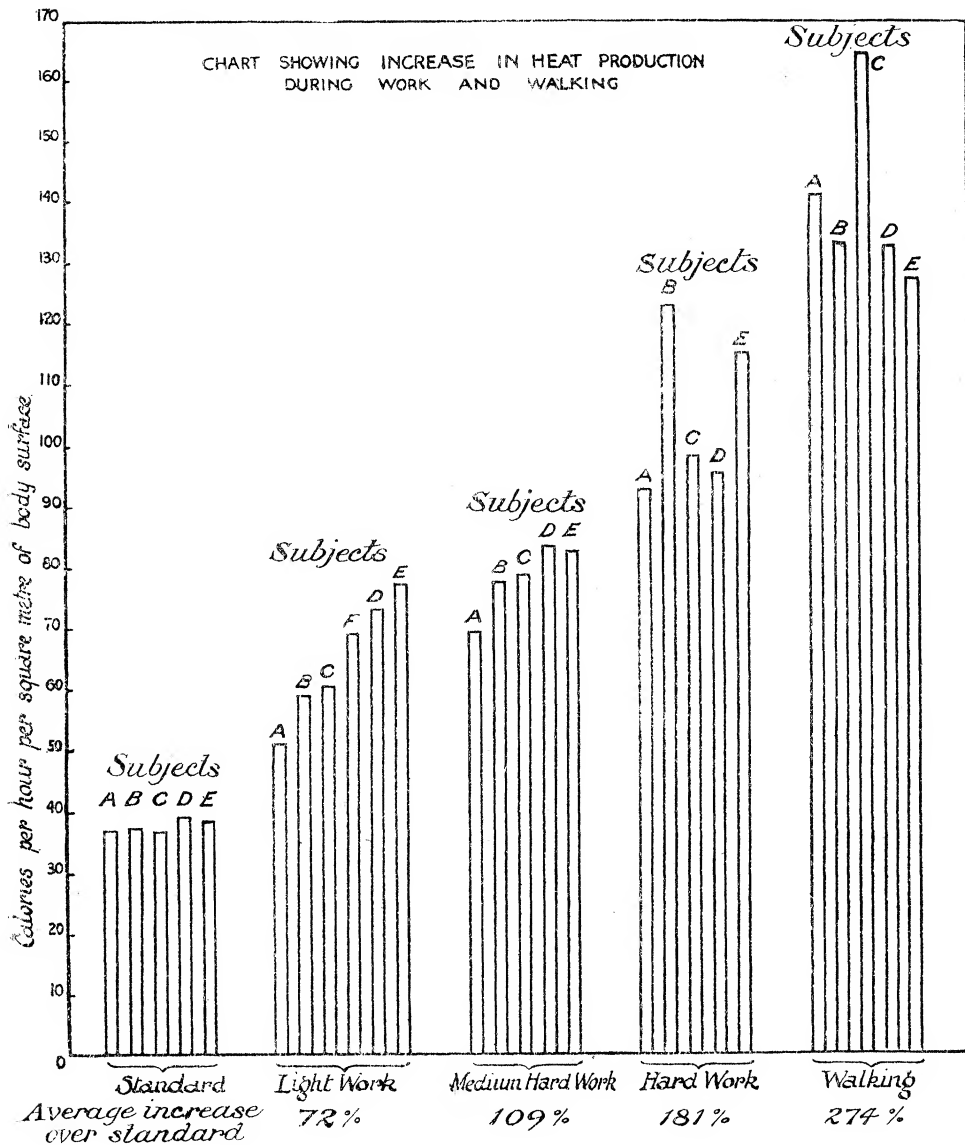
* It has been shown by L. Zuntz, 'Arch. f. Gynäkol.,' vol. 78, p. 106 (1906), that the normal gaseous metabolism is not disturbed by menstruation.

† See G. Lusk, 'Science of Nutrition' (1917), p. 124.

‡ 'Arch. Int. Med.,' vol. 17, p. 863 (1916).

Table I.—Statistical Data of Subjects.

No.	Subject.	Age.	Height.	Weight (without clothes).	Area of body surface.	Previous occupation.	Remarks.
A	Miss E. Lndr.	years. 22	cm. 157·0	kgm. 57·2	sq. metre. 1·566	Cook	Normal, well developed, and muscular. Had 18 months' experience of munition work.
B	Mrs. F. Clvrt.	25	159·5	59·9	1·620	Mill hand	Normal, well developed.
C	Miss M. Ndhm. ...	29	163·0	63·5	1·688	Domestic work	Normal, well nourished and well developed.
D	Miss E. M. Nsh. ...	19	156·5	54·9	1·535	Messenger clerk	Normal, well developed.
E	Miss C. Mrrs.	18	160·8	51·3	1·522	Waitress	Normal, slight build. Had just recovered from three weeks' illness (influenza).
F	Miss A. Wrt.	29	169·4	57·2	1·658	Hospital nurse	Normal, slight build. Found manual work too strenuous and returned to previous occupation.



In the following Table are recorded the results of the experiments on the metabolism during non-working hours:—

Table II.—Metabolism during Non-Working Period.

Sub- ject.	Descrip- tion.	Pulmonary output in litres per minute at 0° and 760 mm.	Pulse.	Respi- ration.	Analysis of expired air.		Carbonic acid eliminated per minute.		Oxygen absorbed per minute.		Respi- ratory quotient.	Calories of heat produced per hour.	
					CO ₂ .	O ₂ .	Total.	Per kgm.	Total.	Per kgm.		Per kgm.	Per square metre of body surface.
A	Standard	4.8	81	10	per cent. 3.81	per cent. 17.05	c.c. 179.8	c.c. 3.15	c.c. 193.1	c.c. 3.38	0.93	0.96	36.7
B	"	5.5	85	20	3.02	17.44	163.5	2.73	198.2	3.31	0.83	0.98	36.8
C	"	5.2	72	16	3.53	17.00	182.0	2.87	210.2	3.31	0.87	0.97	36.5
D	"	6.8	73	20	2.85	18.02	191.2	3.48	199.0	3.63	0.97	1.09	38.9
E	"	5.1	80	12	3.89	17.15	195.9	3.82	191.0	3.72	1.03	1.13	38.2
A	Resting on couch	5.0	77	12	3.78	17.04	188.9	3.31	197.8	3.46	0.96	1.04	37.8
B	"	6.2	79	20	3.17	17.67	198.9	3.22	203.3	3.39	0.95	1.02	37.6
B	"	5.7	80	18	3.48	17.34	195.3	3.26	203.7	3.40	0.96	1.02	37.7
C	"	5.7	—	—	3.69	17.03	205.7	3.24	225.5	3.50	0.92	1.04	39.2
C	"	5.3	85	16	3.60	17.10	190.4	3.00	208.1	3.28	0.92	0.97	36.5
C	"	6.0	—	—	3.54	17.26	210.6	3.32	222.6	3.51	0.95	1.05	39.4
D	"	5.7	81	16	3.17	17.43	180.2	3.28	206.4	3.76	0.87	1.10	39.5
E	"	4.6	79	14	3.89	16.30	182.6	3.56	206.8	4.03	0.88	1.19	39.9
F	"	6.3	—	—	3.25	17.32	201.6	3.53	231.5	4.05	0.87	1.19	40.8
F	"	6.0	—	—	3.04	17.39	181.8	3.18	222.5	3.89	0.82	1.13	38.9
A	Standing	5.8	95	12	3.44	17.18	196.5	3.44	221.3	3.87	0.89	1.14	41.6
B	"	8.3	93	20	2.88	17.77	235.3	3.92	267.7	4.47	0.88	1.31	48.5
C	"	7.0	87	18	3.46	17.02	243.0	3.83	256.1	4.03	0.85	1.18	44.3
D	"	7.7	100	25	2.76	17.84	213.5	3.89	248.8	4.33	0.86	1.34	48.0
E	"	5.6	97	14	3.86	16.47	214.4	4.18	258.9	5.05	0.83	1.47	49.6
A	Sitting	4.4	82	10	4.25	16.01	185.2	3.24	223.9	3.92	0.83	1.13	41.5
B	"	8.3	82	20	3.03	17.81	241.9	4.04	249.8	4.17	0.99	1.26	46.6
C	"	5.5	79	18	3.46	16.91	190.7	3.00	232.6	3.66	0.82	1.06	39.9
D	"	8.3	100	24	2.76	17.98	226.8	4.13	250.1	4.56	0.91	1.35	48.2
E	"	4.9	89	12	4.15	16.58	201.7	3.93	227.1	4.43	0.89	1.31	43.9
A	Walking	14.6	84.2	metres per min. 84.2	4.67	15.92	678.8	11.88	748.4	13.10	0.91	3.88	141.4
B	"	16.7	80.0	80.0	3.95	16.66	655.4	10.94	729.0	12.17	0.90	3.59	133.0
C	"	19.6	78.1	78.1	4.15	16.25	809.7	12.75	949.2	14.95	0.85	4.37	164.2
D	"	18.9	72.7	72.7	3.42	17.36	640.0	11.66	683.0	12.44	0.94	3.71	132.7
E	"	15.5	72.7	72.7	4.19	16.79	644.5	12.56	640.7	12.49	1.01	3.79	127.5

The metabolism during work is shown in the following Table:—

Table III.—Metabolism during Working Period.

Sub- ject.	Description of work.	Type of lathe.	Pulmonary output in litres per minute at 0° and 760 mm.	Analysis of expired air.		Carbonic acid eliminated per minute.		Oxygen absorbed per minute.		Respi- ratory quotient.	Calories of heat produced per hour.	
				CO ₂ .	O ₂ .	Total.	Per kgm.	Total.	Per kgm.		Per kgm.	Per square metre of body surface.
A	Light (turning)	7" centre	6.6	per cent. 3.64	per cent. 16.90	c.c. 238.5	c.c. 4.37	c.c. 273.5	c.c. 4.79	0.87	1.38	50.6
B	" (screw chasing)	6"	9.9	3.41	17.56	318.8	5.32	318.8	5.32	1.00	1.61	59.6
C	" (parting)	"	9.1	3.21	17.35	289.4	4.56	345.1	5.43	0.87	1.59	60.1
D	" (parting)	9"	11.4	3.11	17.74	350.9	6.40	367.2	6.69	0.96	2.00	71.6
D	" (screw chasing)	7"	12.3	2.95	17.84	358.7	6.54	385.2	7.02	0.93	2.09	74.7
E	" (screw cutting)	7"	11.6	3.34	17.55	384.9	7.50	406.9	7.93	0.95	2.37	79.9
E	" (recessing)	7"	10.9	3.43	17.41	369.7	7.21	386.3	7.53	0.96	2.26	76.0
E	" (screw chasing)	7"	12.2	3.24	17.73	392.6	7.65	392.6	7.65	1.00	2.32	78.1
E	" (turning)	No. 4 capstan	11.3	3.27	17.70	366.9	7.15	366.9	7.15	1.00	2.17	73.0
F	" (parting)	7" centre	10.2	3.61	17.24	365.2	6.39	379.6	6.64	0.96	1.99	68.6
F	" (turning)	7"	10.7	3.54	17.35	367.7	6.59	386.4	6.76	0.98	2.03	70.2
F	" (screw cutting)	7"	10.8	3.28	17.45	351.0	6.14	382.4	6.69	0.92	1.98	68.4
A	Medium hard (boring)	7"	9.4	3.69	17.13	344.4	6.03	361.4	6.39	0.95	1.89	69.1
A	" (rough turning)	7"	9.3	3.62	17.06	334.8	5.86	367.9	6.44	0.91	1.91	69.8
B	" (turning)	7"	11.9	3.31	17.63	391.7	6.54	396.8	6.62	0.99	1.99	73.9
B	" (boring)	7"	12.4	3.54	17.42	435.2	7.27	435.2	7.27	1.00	2.19	81.3
C	" (turning)	7"	11.1	3.48	17.15	382.9	6.03	430.7	6.78	0.89	2.00	75.4
C	" (boring)	No. 4 capstan	14.6	3.80	16.77	412.0	6.49	466.1	7.35	0.88	2.15	81.1
D	" (boring)	7" centre	13.7	2.98	17.88	405.2	7.38	422.9	7.71	0.96	2.31	82.6
D	" (rough turning)	7"	13.9	2.92	17.82	402.8	7.34	441.6	8.05	0.91	2.39	85.3
E	" (turning)	9"	11.9	3.49	17.47	413.6	8.07	413.6	8.07	1.00	2.44	82.3
A	Filing (60 strokes per minute)	"	12.8	4.12	16.88	525.4	9.19	518.6	9.08	1.01	2.75	100.5
A	Hard (12 turns of capstan)	No. 4 capstan	11.6	3.74	16.81	433.2	7.58	493.4	8.63	0.88	2.54	92.6
B	" (boring)	No. 9 capstan	17.5	3.65	17.12	632.8	10.56	675.3	11.27	0.94	3.44	124.7
C	" (boring from headstock)	9" centre	14.7	3.53	17.19	513.8	8.09	558.5	8.80	0.92	2.61	98.1
D	" (rough turning, hand-feed)	9"	15.0	3.16	17.59	471.0	8.59	511.4	9.32	0.92	2.77	98.9
D	" (10 turns of capstan)	No. 4 capstan	13.9	3.05	17.52	449.3	8.19	487.5	8.88	0.86	2.59	92.9
E	" (boring)	No. 9 capstan	15.0	3.66	17.04	542.9	10.58	592.3	11.55	0.92	3.43	115.4

Discussion of Results.

(a) *Standard Metabolism.*—An examination of the Tables brings out a remarkable agreement in the figures for the standard metabolism *inter se* and with the results in the literature so far as they can be used for comparison. The investigations of Benedict and Emmes,* in which previous work is also discussed, supplies the largest amount of material for comparison, containing the results of experiments on 68 women. By applying Du Bois formula to the data available F. C. Gephart and E. F. Du Bois† give 37 calories per hour per square metre (with ± 10 per cent. maximum variation from the mean) as the average “basal” heat production of adult women between the ages of 20–50 years. The average of the five experiments above described is 37·4 calories with a maximum variation of from $-2\cdot5$ per cent. to $+4$ per cent., using the Du Bois formula. Considering that these results were obtained by different methods, the agreement is sufficiently close to furnish a further confirmation of the claims made for the contention that the unit of surface area eliminates the same amount of heat in the normal adult, the figure for women being about 7 per cent. lower than that for men. As equal care to guard against all avoidable errors was taken in the subsequent experiments on work, it may be assumed that they are at least equally correct, and that their relatively small number does not materially affect the reliability of the general conclusions drawn from them.

(b) *Metabolism during Non-working Hours.*—The figures obtained in the resting, but not post-absorptive condition, are mainly of interest as showing how little the metabolism under these conditions differs from the standard metabolism. As the experiments were usually made from 3–4 hours after a light breakfast, the stimulating effect of the food ingestion had already passed off to a large extent. Subjects D and E show somewhat higher results than the others in the “sitting” and “standing” experiments, but since the metabolism of these subjects seems to be generally on a higher plane, this result is not remarkable. The pulse rate of Subject D happened in these experiments to be unusually high, but its relationship to the respiration rate together with the absence of any other symptoms do not justify the assumption that her condition was not what would usually be called “normal.”

The energy expenditure of women during walking has not so far formed the subject of any investigation, and the amplified analysis of the “walking” experiments as shown in the following Table may, therefore, not be out of place:—

* ‘Journ. Biol. Chem.,’ vol. 20, p. 253 (1915).

† ‘Arch. Int. Med.,’ vol. 17, p. 902 (1916).

Table IV.—Analysis of Walking Experiments.

Sub- ject.	(a) Weight (with clothing). kgm.	(b) Velocity. Metres per min.	(c) Horizontal kgm.-metre. (a × b.)	(d) Increase of heat output during walking (= Walking - Standard). Calories per min.	Energy requirement for moving horizontally 1 kgm. body-weight for a distance of 1 metre.	
					Grm. cal. (d ÷ c).	Kgm.-metre.
A	59·7	84·2	5·027	2·73	0·543	0·231
B	62·4	80·0	4·992	2·62	0·525	0·224
C	66·0	78·1	5·155	3·59	0·696	0·294
D	57·4	72·7	4·173	2·39	0·573	0·244
E	53·8	72·7	3·911	2·27	0·580	0·247

The subjects walked at an easy ordinary rate which varied in the different individuals from 73 to 84 metres per minute (2·7 to 3·1 miles per hour). The so-called "maximal economic velocity" in horizontal walking for men is at the rate of 80 to 85 metres per minute. Judging by the figures available in the literature, which need not here be gone into, the results show that women expend practically the same amount of energy as men in moving horizontally 1 kilo. body weight through a distance of 1 metre.

The results when represented graphically (see Chart) illustrate the variations which are usually found in different subjects during walking and also the effect of occupational training. This is most obvious in the case of Subject E, whose low total energy expenditure in walking may be directly traced to the training received in her previous occupation as waitress.*

The chart further reveals the interesting fact that the energy expenditure during one hour's horizontal walking is in all cases higher than that of even the hardest work on the lathe.

(c) *Metabolism during Work.*—The following Table (Table V) contains a compilation of the data for the total metabolism per hour and its increase over the standard metabolism due to various forms of work. The last column shows the relative increase, taking the standard metabolism as the unit. An inspection of the chart, representing the results in a graphic form and arranged according to the calorie expenditure of the individual subjects, shows that during "light" work their energy expenditure stands in a certain relationship, which is still maintained in the same order during "medium hard" work. During "hard" work, however, the energy expenditure of the

* It is interesting to note the general agreement of these figures with the old experiments of Edward Smith on himself (*loc. cit.*), who found an increase of 2·5 to 3·5 times his basal metabolism, when walking horizontally at the rate of from 2 to 3 miles per hour.

Table V.—Metabolism per Hour and Increase during Work (compared with Standard Metabolism).

Subject.	Description.	CO ₂ eliminated.		O ₂ absorbed.		Heat produced in calories.			Work performed.*	Heat increase. (Standard = 1.)
		Total.	Per sq. m.	Total.	Per sq. m.	Total.	Per kgm.	Per sq. m.		
A	Standard	gm. 21.2	gm. 13.5	gm. 16.6	gm. 10.6	57.5	0.96	36.7	kgm. —	1.00
A	Light work	28.1	17.9	23.5	15.0	79.2	1.38	50.6	1,900	0.38
	Increase	6.9	4.4	6.9	4.4	21.7	0.42	13.9	—	
A	Medium hard work†	40.0	25.5	31.3	20.0	108.6	1.90	69.5	4,570	0.89
	Increase	18.8	12.0	14.7	9.4	51.1	0.94	32.8	—	
A	Hard work	51.1	32.6	42.3	27.0	144.9	2.54	92.6	7,600	1.52
	Increase	29.9	19.1	25.7	16.4	87.4	1.58	55.9	—	
A	Metal filing	61.9	39.5	44.5	28.4	157.3	2.75	100.5	9,320	1.74
	Increase	40.7	26.0	27.9	17.8	99.8	1.79	63.8	—	
A	Walking 3.1 miles per hour	80.0	51.1	64.2	41.0	221.5	3.88	141.5	14,580	2.85
	Increase	58.8	37.6	47.6	30.4	164.0	2.92	104.7	—	
B	Standard	19.3	11.9	17.0	10.5	58.4	0.98	36.8	3,860	0.62
B	Light work	37.6	23.2	27.3	16.9	96.5	1.61	59.6	—	
	Increase	18.3	11.3	10.3	6.4	38.1	0.63	22.8	6,520	1.11
B	Medium hard work†	48.8	30.1	35.7	22.0	125.8	2.09	77.6	—	
	Increase	29.5	18.2	18.7	11.5	67.4	1.11	40.8	13,100	2.38
B	Hard work	74.6	46.1	57.9	35.7	201.4	3.44	124.7	—	
	Increase	55.3	34.2	40.9	25.2	143.0	2.46	87.9	14,120	2.61
B	Walking 2.98 miles per hour	77.3	47.7	62.5	38.6	215.3	3.59	133.0	—	
	Increase	58.0	35.8	45.5	28.1	156.9	2.61	96.2	—	

C	Standard	21.5	12.7	18.0	10.6	61.6	0.97	36.5	3,320	0.65
C	Light work	34.1	20.2	29.6	17.5	101.4	1.59	60.1	—	—
	Increase	12.6	7.5	11.6	6.9	39.8	0.62	23.6	—	—
C	Medium hard work†	46.9	27.8	38.5	22.8	132.0	2.08	78.2	6,270	1.14
	Increase	25.4	15.1	20.5	12.2	70.4	1.11	41.7	—	—
C	Hard work	60.6	35.9	47.9	28.4	165.6	2.61	98.1	9,400	1.68
	Increase	39.1	23.2	29.9	17.8	104.0	1.64	61.6	—	—
C	Walking 2.9 miles per hour	95.5	56.6	81.4	48.2	277.2	4.37	164.2	18,750	—
	Increase	74.0	43.9	63.4	37.6	215.6	3.40	127.7	—	3.59
D	Standard	22.5	14.7	17.1	11.1	59.7	1.09	38.9	—	—
D	Light work†	41.8	27.2	32.3	21.0	112.3	2.05	73.2	4,710	0.88
	Increase	19.3	12.5	15.2	9.9	52.6	0.96	34.3	—	—
D	Medium hard work†	47.6	31.0	37.1	24.2	128.8	2.35	83.9	6,150	1.16
	Increase	25.1	16.3	20.0	13.1	69.1	1.26	45.0	—	—
D	Hard work	54.3	35.4	42.9	28.0	147.3	2.68	95.9	7,870	1.47
	Increase	31.8	20.7	25.8	16.9	87.6	1.59	57.0	—	—
D	Walking 2.7 miles per hour	75.5	49.2	58.6	38.2	203.6	3.71	132.7	12,890	—
	Increase	53.0	34.5	41.5	27.1	143.9	2.62	93.8	—	2.41
E	Standard	23.1	15.2	16.4	10.8	58.1	1.13	38.2	—	—
E	Light work†	44.6	29.3	33.3	21.9	116.8	2.28	76.8	5,240	1.01
	Increase	21.5	14.1	16.9	11.1	58.7	1.11	38.6	—	—
E	Medium hard work	48.8	32.1	35.5	23.3	125.2	2.44	82.3	6,080	1.15
	Increase	25.7	16.9	19.1	12.5	67.1	1.31	44.1	—	—
E	Hard work	64.0	42.0	50.8	33.4	175.6	3.43	115.4	10,300	2.02
	Increase	40.9	26.8	34.4	22.6	117.5	2.30	77.2	—	—
E	Walking 2.7 miles per hour	76.0	49.9	54.9	36.1	194.0	3.79	127.5	12,420	—
	Increase	52.9	34.7	38.5	25.3	135.9	2.66	89.3	—	2.33

* Average of results calculated from the increase of CO₂ and O₂. The factors determined by Benedict and Carpenter (Carnegie Institution Publications, No. 126, 1910) were used.

† Average of four experiments.

† Average of two experiments.

different subjects is more variable, but, in all forms of work, Subject A, probably owing to her previous training as munition worker, performed the work with a minimum expenditure of energy. The work economy of this subject is also seen in the experiment in which she performed the relatively strenuous work of metal filing (60 strokes per minute), and in which her energy expenditure only rose slightly, over that of the hardest work on the lathe (see Table III). The general results of the work experiments lead to the conclusion, which might not *a priori* be expected, that the energy required for lathe working is relatively small.

The Daily Food Requirements of Lathe Workers.

By means of the data obtained, although they are not perhaps sufficiently numerous to warrant final conclusions, we may arrive at an approximate estimate of the food requirements, expressed in calories, of the women who formed the subjects of this inquiry. The following Table (Table VI) shows the energy expenditure of the subjects in the three periods of sleep, work, and recreation, calculated on the basis of the considerations set forth in the introduction. The sum of these, multiplied with the figure for the total body surface of the subject in each case, represents what might be termed the "net" calorie requirements, and an increase of 15 per cent. on this figure represents the corresponding calorie values of the food as purchased.

It will be seen that the final figures show that the calorie values of the food required by women engaged on lathe work vary from 2400 to 2800 calories. It is interesting to compare this result with the recommendations made by L. E. Hill and his co-workers, based on their statistical inquiries.* For a man on moderate munition work, 3000-3500 calories per day were suggested as a standard, the corresponding figure for women being 2400-2800 calories. The absolute agreement of the figures obtained by these two inquiries, based on entirely different methods, seems to be more than an accidental coincidence. It is hardly necessary to point out that, in assessing the food requirements of women workers, due consideration must be paid not only to the quantitative side, as dealt with above, but also to the qualitative side, in respect to the presence in adequate amounts of the all-important accessory factors or vitamins.

* See Memorandum No. 19, 'Health of Mun. Work. Com.,' 1917.

Table VI.—Food Requirements (in Calories) per 24 Hours.

	Miss Lndr.	Mrs. Clvrt.	Miss Ndhm.	Miss Nsh.	Miss Mrs.
8 h. sleep (= 8 × standard metabolism)	293·6	294·4	292·0	311·2	305·6
8 h. work { 2 h. hard work	185·2 } 545·8	249·4 } 678·0	196·2 } 629·4	191·8 } 663·4	230·8 } 708·4
..... { 6 h. average of light and medium work...	360·6 }	429·6 }	433·2 }	471·6 }	477·6 }
8 h. recreation { 1·5 h. walking	212·1 }	199·5 }	246·3 }	194·1 }	191·3 }
..... { 3·5 h. sitting	145·3 }	163·1 }	139·7 }	168·7 }	153·7 }
..... { 3 h. standing	124·8 }	145·5 }	132·9 }	144·0 }	148·8 }
Total per sq. m. of body surface	1321·6	1480·5	1440·3	1481·4	1507·8
Net calories*	2070	2400	2430	2275	2800
Gross calories†	2380	2760	2800	2620	2640

* = calories for total body surface.

† = Net calories + 15 per cent. increase.

APPENDIX.

Table I.—Kata-thermometer Observations.

Place.	Kata thermometer time in seconds for fall from 37.8°-32.2° C.		Rate of heat loss (per second) of 1 sq. cm. surface at 36° C., grm. cal.		Thermometer.		Relative humidity.	Baro- meter.	Remarks.
	Wet.*	Dry.*	By radiation, convection, and evaporation.	By evaporation.	Wet bulb.	Dry bulb.	Per cent.	mm.	
Aero-shop, centre	32	75	16.2	9.3	14.2	17.5	68	761.2	Engine going, fire ventilators open.
Preliminary shop, near door	26	58	19.9	11.0	12.9	15.1	76	761.2	Engine going, one ventilator open.
Preliminary shop, centre	29	70	17.8	10.4	13.0	15.0	78	761.2	Engine going, one ventilator open.
Same day on roof of King's College	14	19	36.9	9.7	10.2	11.9	80	761.2	Cloudy, S.W. breeze.
Aero-shop, centre	68	173	7.6	4.7	14.5	17.5	70	762.5	Engine going, one ventilator open.
Same day on roof of King's College	27	48	19.2	8.4	10.0	12.0	77	762.5	Dull, W. wind.

* Average of three readings.

Table II.—Test of Douglas Bag.

The expired air was collected during a period of five minutes from a subject sitting on a chair. Volume 31·4 l. (corr.). Samples were taken from the bag and analysed in the intervals given in the Table. The subject's body-surface area was 1·72 sq. m. (height = 166·5 cm., weight = 64 kgrm.).

Analysis of Expired Air.

Time.	CO ₂ .	O ₂ .	N.
h.	Per cent.	Per cent.	Per cent.
0	4·015 } 4·00	16·75 } 16·75	79·25
1	3·993 } 3·92	16·75 } 16·75	79·33
2	3·916 } 3·87	16·77 } 16·73	79·40
5	3·919 } 3·83	16·74 } 16·73	79·42
22	3·871 } 3·47	16·72 } 16·89	79·64
	3·865 } 3·47	16·74 } 16·89	
	3·826 } 3·47	16·73 } 16·89	
	3·835 } 3·47	16·73 } 16·89	
	3·456 } 3·47	16·87 } 16·89	
	3·474 } 3·47	16·90 } 16·89	

The following table shows that the final result is not appreciably affected until after two hours from the beginning of the experiment :—

Time.	R.Q.	CO ₂ eliminated per min.	O ₂ absorbed per min.	Calories of heat produced per hour.		Error.
				Per kgrm.	Per sq. m.	
h.		c.c.	c.c.			Per cent.
0	0·93(7)	249·3	266·1	1·23(9)	46·15	—
1	0·91(4)	242·3	265·2	1·24(4)	46·29	+0·30
2	0·89(4)	241·2	269·9	1·24(4)	46·28	+0·28
5	0·88(8)	238·6	268·8	1·21(5)	45·09	—2·30
22	0·81(9)	216·0	263·7	1·19(1)	44·32	—3·96

Table III.—Comparison of Face Mask and Mouthpiece.

	Pulmonary output, litres per min.	Pulse.	Respira- tion.	Analysis of expired air.		CO ₂ eliminated per min.	O ₂ absorbed per min.	R.Q.	Calories of heat produced per hour.	
				CO ₂ .	O ₂ .				Per kgrm.	Per sq. m.
Mouthpiece	6·4	67	10	per cent. 4·02	per cent. 16·93	c.c. 258·2	c.c. 248·9	0·99	1·22	45·6
Face mask ...	6·0	74	11	4·08	16·67	241·9	257·9	0·94	1·20	44·7

The experiments were made on different days. The subject was sitting on a chair. Subject's body surface 1·72 sq. m. (weight 64 kgrm., height 166·5 cm.). To save space only two of six similar experiments are given.